UNIVERSITI SAINS MALAYSIA

Peperiksaan Semester Pertama
Sidang Akademik 2004/2005

Oktober 2004

EKC 212 – Aliran Bendalir Kejuruteraan Kimia

Masa : 3 jam

Sila pastikan bahawa kertas peperiksaan ini mengandungi SEPULUH muka surat yang bercetak dan LIMA muka surat Lampiran sebelum anda memulakan peperiksaan ini.

Arahan: Jawab **EMPAT (4)** soalan. Jawab **SEMUA** soalan dari Bahagian A. Jawab mana-mana **DUA (2)** soalan dari Bahagian B.

Pelajar boleh menjawab semua soalan dalam Bahasa Malaysia. Jika pelajar ingin menjawab dalam Bahasa Inggeris, pelajar hendaklah menjawab sekurang-kurangnya SATU soalan dalam Bahasa Malaysia.

Bahagian A – Jawab SEMUA soalan.
Section A - Answer ALL questions.

1. [a] Suatu bendalir mempunyai sifat-sifat berikut:

- Haba tentu,	$C_P = 0.61$ kal/g^{o}C
- Ketumpatan,	$\rho = 920$ kg/m^3
- Kelikatan,	$\mu = 0.64$ cP

Tukarkan sifat-sifat tersebut ke unit berikut:

[i] C_P dalam unit S.I dan ENG

[ii] ρ dalam unit ENG dan B.G (Graviti British)

[iii] μ dalam unit S.I dan ENG

[6 markah]

[b] Terbitkan persamaan Hidrostatik Bernoulli.

[6 markah]

[c] Suatu penyelidikan menunjukkan bahawa suhu bagi atmosfera bumi jatuh pada kadar 10^{o}C bagi setiap 1000 m ketinggian dari permukaan bumi. Sekiranya suhu udara di kampus kita ialah 28^{o}C dan bertekanan 1 atm, pada ketinggian berapakah tekanan adalah 400 mmHg. [Pemalar gas R = 8.314 kJ.K/kmol, dan berat molekul udara MW = 29 kg/kg-mol].

[8 markah]

1. [a] A liquid has the following properties:

- Specific heat,	$C_P = 0.61$ *cal/g^{o}C*
- Density,	$\rho = 920$ *kg/m^3*
- Viscosity,	$\mu = 0.64$ *cP*

Convert its properties to the following unit systems:

[i] C_P into S.I and ENG unit

[ii] ρ into ENG and B.G (British Gravity) unit

[iii] μ into S.I and ENG unit

[6 marks]

[b] Derive the Bernoulli Hydrostatic Equation

[6 marks]

[c] A research shows that the temperature of the earth atmosphere drops at 10^{o}C for every 1000 m of elevation above the earth surface. If the air temperature at our Campus is 28^{o}C and the pressure is 1 atm, at what height (elevation) is the pressure 400 mmHg. [Gas constant, R = 8.314 kJ.K/kmol, and MW for air = 29 kg/kg-mol]

[8 marks]

...3/-

2. [a] Betul atau salah

[i] Untuk aliran sesuhu bagi gas boleh mampat di dalam talian paip, kadar aliran jisim berkadaran dengan kejatuhan tekanan bagi paip yang mempunyai kepanjangan terhingga.

[ii] Untuk kebanyakan rekabentuk pam emparan, turusnya meningkat apabila aliran meningkat.

[iii] Kesferaan sebuah kiub lebih besar daripada sebuah sfera yang mempunyai isipadu yang sama.

[iv] Persamaan Ergun boleh digunapakai bagi aliran laminar dan turbulen.

[v] Bagi aliran turbulen disekeliling sebuah sfera, pekali seretan adalah lebih besar daripada yang dijangkakan oleh hukum Stokes.

[iv] Di dalam operasi lapisan terbendalir, pecahan isipadu pepejal meningkat apabila ketinggian lapisan bertambah.

[6 markah]

[b] Kenapa pengetahuan tentang halaju terminal penting di dalam operasi lapisan terbendalir?

[3 markah]

[c] Apakah peronggaan pam dan apakah penyebabnya?

[3 markah]

[d] Sebuah lapisan terpadat 1 m^3 terdiri daripada zarah silinder mempunyai garispusat 0.002 m dan panjangnya sama dengan garispusat. Jumlah jisim lapisan tersebut adalah 962 kg dan ketumpatan zarah silinder pepejal adalah 1600 kg/m^3.

[i] Kirakan pecahan lompang

[ii] Kirakan nisbah permukaan kepada isipadu zarah

[iii] Kirakan garispusat berkesan bagi zarah

[8 markah]

2. *[a] True or False*

[i] For isothermal flow of a compressible gas in a pipeline, the mass flow rate is proportional to pressure drop for a finite length of pipe.

[ii] For most designs of centrifugal pumps,, the head increases as the flow rate increases.

[iii] *The sphericity of a cube is greater than that of a sphere of the same volume.*

[iv] *The Ergun equation applies for both laminar and turbulent flows.*

[v] *For turbulent flow around a sphere, the drag coefficient is greater than that predicted by Stokes law.*

[vi] *In fluidized bed operations, volume fraction of solids increases as bed height increases.*

[6 marks]

[b] *Why is the knowledge of the terminal velocity important in fluidized bed operations?*

[3 marks]

[c] *What is pump cavitation, and what is its cause?*

[3 marks]

[d] *A 1 m^3 of packed bed is composed of cylindrical particles having diameter 0.002 m and a length equal to the diameter. The total mass of the bed is 962 kg and the density of the solid cylindrical particles is 1600 kg/m^3.*

[i] *Calculate the void fraction.*

[ii] *Calculate the surface to volume ratio of the particles.*

[iii] *Calculate the effective diameter of the particles.*

[8 marks]

<u>Bahagian B</u> - Jawab mana-mana <u>DUA</u> soalan.
<u>Section B</u> - Answer any <u>TWO</u> questions

3. [a] Bagi suatu bendalir Newton yang tak boleh dimampatkan yang mengalir dalam sebuah paip, terbitkan ungkapan berikut:

$$\frac{U}{U_{max}} = 1 - \left[\frac{r}{r_w}\right]^2$$

di mana :

U = profil halaju setempat
U_{max} = halaju maksimum dalam paip
r = jejari setempat dalam paip
r_w = jejari paip

[5 markah]

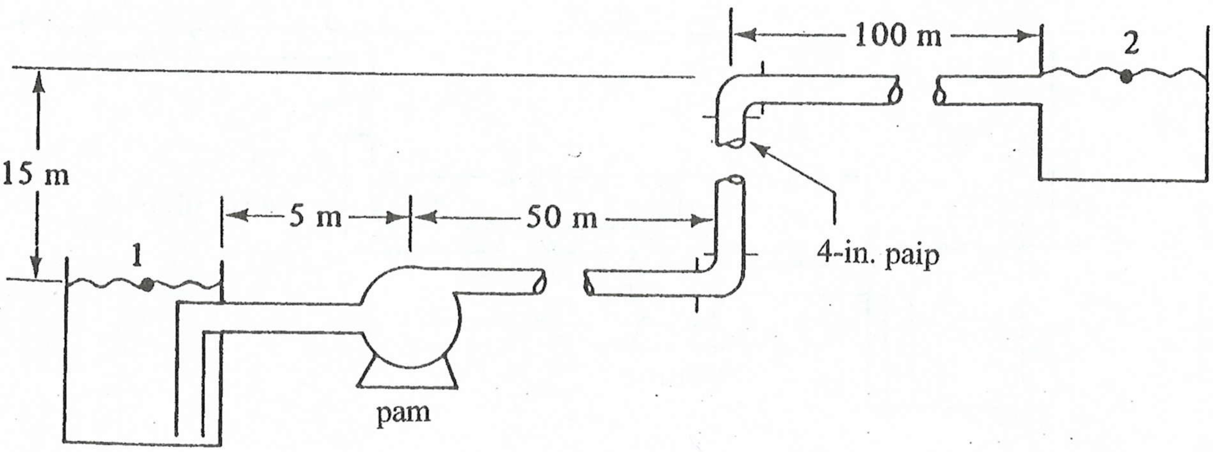
[b] Satu paip keluli bergarispusat 2 ft membawa air pada kadar 15 ft/s. Kekasaran permukaan paip ialah 0.0003 ft. Kemudian, suatu lapisan plastik yang licin dimasukkan ke dalam paip yang mengurangkan garis pusat dalamannya kepada 1.9 ft. Tentukan perubahan-perubahan pengaliran di dalam paip dengan mengira:

[i] Perubahan kejatuhan tekanan pada kadar aliran yang sama

[ii] Perubahan kapasiti (kadar aliran isipadu) pada kejatuhan tekanan yang sama

[10 markah]

[c] Air pada 20°C dipam dari suatu tangki kepada tangki yang berada pada aras yang lebih tinggi pada kadar 5 x 10^{-3} m^3/s seperti yang ditunjukkan dalam Gambarajah S.3. Kesemua sistem paip yang ditunjukkan adalah paip 4-in schedule 40. Kirakan kuasa (kW) yang diperlukan oleh pam. Kecekapan keseluruhan pam ialah 65%.



Gambarajah S. 3

[15 markah]

3. [a] *For an incompressible and Newtonian fluid flowing in a pipe, derive the following expression.*

$$\frac{U}{U_{max}} = 1 - \left[\frac{r}{r_w}\right]^2$$

where :

U = *local vecocity profile*
U_{max} = *maximum velocity in the pipe*
r = *local radius in the pipe*
r_w = *radius of the pipe (wall)*

[5 marks]

[b] *A steel pipe 2 ft diameter carries water at 15 ft/s. The roughness of the pipe is 0.0003 ft. Later, a smooth plastic liner is inserted in the pipe which reduces the inside diameter to 1.9 ft. Determine the changes in the pipe flow by calculating:*

[i] *The change in pressure drop for the same flow.*

[ii] *The change in capacity (volumetric flowrate) for a fixed pressure drop.*

[10 marks]

[c] *Water at 20°C is being pumped from a tank to an elevated tank at the rate of 5×10^{-3} m^3/s as shown in Figure Q.3. All the piping system in the figure is 4-in schedule 40 pipe. Calculate the kW power needed for the pump. The overall efficiency of the pump is 65%.*

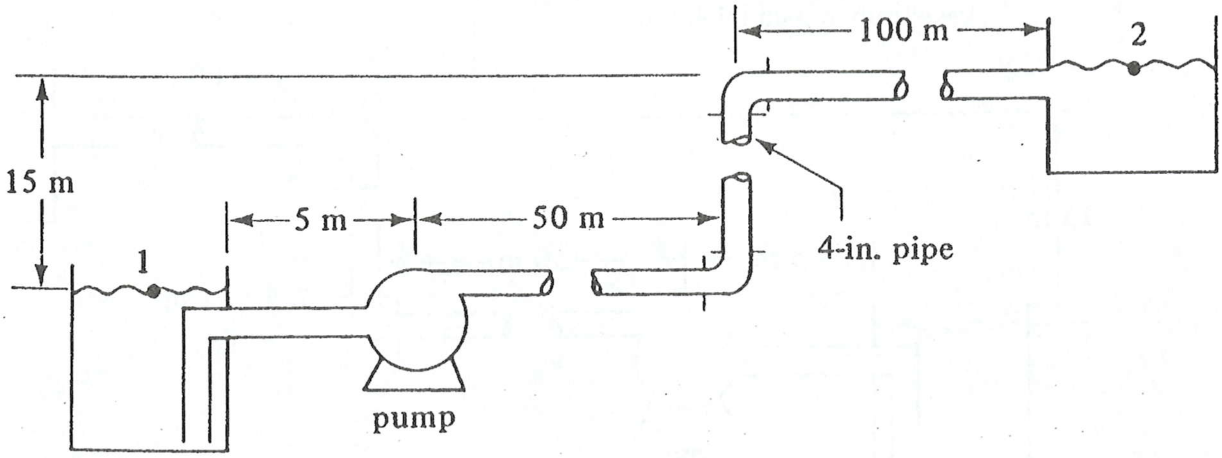


Figure Q. 3

[15 marks]

4. Metana (jisim molar = 16) dipindahkan melalui talian paip keluli 200-mm ID (keluasan paip keluli = 0.046 mm) pada kadar 450 std m^3/minit. Gas memasuki talian pada tekanan mutlak 45 atm. Anggap gas unggul dan aliran sesuhu pada 30°C. Kelikatan metana pada 30°C adalah 0.014 cP.

[a] Apakah tekanan pada jarak 80 km dari kemasukan?

[8 markah]

[b] Stesen pemampat ditempatkan pada setiap 80 km untuk menaikkan semula tekanan kepada 45 atm mutlak. Jika pemampat-pemampat adalah adiabatik dengan kecekapan 65%, apakah kuasa yang diperlukan bagi setiap pemampat?

[6 markah]

[c] Jika setiap pemampat di dalam bahagian [b] mempunyai dua peringkat, apakah suhu keluaran pada setiap peringkat?

[6 markah]

[d] Berapa jauhkah jarak stesen pemampat boleh ditempatkan sebelum alirannya di dalam talian paip tercekik.

[10 markah]

Persamaan berikut diberikan:

$$P_1^2 - P_2^2 = \frac{G^2 RT}{M}\left[2\ln\frac{\rho_1}{\rho_2} + \frac{fL}{r_H}\right]$$

$$G^* = P_2^* \sqrt{M/(RT)}, \quad P_2^* = P_1 \mathrm{Ma}_1 \sqrt{\gamma}, \quad \mathrm{Ma} = \frac{u}{\sqrt{\gamma RT/M}}$$

$$W = \frac{RT_1\gamma}{M(\gamma-1)}\left[\left(\frac{P_2}{P_1}\right)^{(\gamma-1)/\gamma} - 1\right], \qquad \gamma = 1.31$$

4. *Methane (molar mass = 16) is transported through a 200-mm ID steel pipeline (roughness = 0.046 mm) at a rate of 450 std m³/min. The gas enters the line at an absolute pressure of 45 atm. Assume ideal gas and isothermal flow at 30°C. Viscosity of methane at 30°C is 0.014 cP.*

[a] What is the pressure 80 km away from the entrance?

[8 marks]

[b] A compressor station is located every 80 km to boost the pressure back up to 45 atm abs. If the compressors are adiabatic with an efficiency of 65%, what is the required power for each compressor?

[6 marks]

[c] If the compressors in part [b] are each two-stage, what is the discharge temperature from each stage?

[6 marks]

[d] How far apart could the compressor stations be located before the flow in the pipeline becomes choked?

[10 marks]

The following equations are given:

$$P_1^2 - P_2^2 = \frac{G^2 RT}{M}\left[2\ln\frac{\rho_1}{\rho_2} + \frac{f\,L}{r_H}\right]$$

$$G^* = P_2^* \sqrt{M/(RT)}, \qquad P_2^* = P_1 \mathrm{Ma}_1 \sqrt{\gamma}, \qquad \mathrm{Ma} = \frac{u}{\sqrt{\gamma RT/M}}$$

$$W = \frac{RT_1\gamma}{M(\gamma-1)}\left[\left(\frac{P_2}{P_1}\right)^{(\gamma-1)/\gamma} - 1\right], \qquad \gamma = 1.31$$

5. [a] Pengoksidaan separa dijalankan dengan melalukan udara yang mengandungi 1 mol% hidrokarbon melalui tiub menegak berketinggian 2 m dan I.D. 40-mm dan ianya dipadatkan dengan pelet mangkin 1 mm. Udara memasuki lapisan dari bawah pada 200°C dan 2 atm mutlak. Ketumpatan pelet mangkin adalah 960 kg/m^3 dan kesferaannya adalah 0.86. Reaktor beroperasi pada suhu 200°C sesuhu. Anggap pecahan lompang (ε) lapisan terpadat = 0.40. Jisim molar purata bagi udara yang megandungi hidrokarbon adalah 30. Kelikatan udara pada 200°C adalah 2.6 x 10^{-5} Pa.s.

[i] Jika udara memasuki dengan halaju permukaan 0.15 m/s, apakah tekanan keluaran dari lapisan terpadat? Apakah masa tembungan antara gas dan pelet mangkin?

[6 markah]

[ii] Apakah kadar aliran udara yang secukupnya untuk membendalirkan pepejal.

[8 markah]

[iii] Apakah halaju yang diperlukan untuk membendalirkan lapisan sebanyak 20%. Anggapkan persamaan Ergun masih boleh digunakan untuk lapisan yang sedikit terbendalir.

[8 markah]

Persamaan berikut diberikan:

$$\frac{\Delta P}{L} = \frac{150\overline{V}_0\mu}{\Phi_s^2 D_p^2}\frac{(1-\varepsilon)^2}{\varepsilon^3} + \frac{1.75\rho\overline{V}_0^2}{\Phi_s D_p}\frac{1-\varepsilon}{\varepsilon^3}$$

$$\Phi_s \varepsilon_{mf}^3 \cong 1/14$$

[b] Meter orifis mempunyai diameter leher 40 mm ditempatkan di dalam talian paip mengufuk I.D. 75-mm. Air pada 25°C mengalir melalui talian paip. Manometer mengandungi merkuri mengukur tekanan kebezaan melintasi meter orifis. Apabila bacaan manometer adalah 50 mm, apakah kadar alirannya di dalam m^3/h?. Kelihatan air pada 25°C adalah 0.9 cP. Pekali luahan orifis boleh diambil sebagai 0.61 bagi $Re_0 > 30,000$.

$$u_o = \frac{C_o}{\sqrt{1-\beta^4}}\sqrt{\frac{2(P_1 - P_2)}{\rho}}$$

[8 markah]

5. [a] *A partial oxidation is carried out by passing air containing 1 mol% hydrocarbon through 40-mm I.D. 2 m height vertical tubes packed with 1 mm catalyst pellets. The air enters the bed from the bottom at 200°C and 2 atm abs. The density of the catalyst pellets is 960 kg/m^3 and their sphericity is 0.86. The reactor operates at isothermal temperature of 200°C. Assume void fraction (ε) of packed bed = 0.40. The average molar mass of hydrocarbon-laden air is 30. The viscosity of air at 200°C is 2.6 x 10^{-5} Pa.s.*

[i] *If the air enters with a superficial velocity of 0.15 m/s, what is the outlet pressure from the packed bed? What is contact time between the gas and catalyst pellets?*

[6 marks]

[ii] *What will be the flow rate of air that is just enough to fluidize the solids?*

[8 marks]

[iii] *What velocity is required to expand the bed by 20%? Assume that the Ergun equation still holds for the slightly expanded bed*

[8 marks]

The following equations are given:

$$\frac{\Delta P}{L} = \frac{150\overline{V}_0\mu}{\Phi_s^2 D_p^2}\frac{(1-\varepsilon)^2}{\varepsilon^3} + \frac{1.75\rho\overline{V}_0^2}{\Phi_s D_p}\frac{1-\varepsilon}{\varepsilon^3}$$

$$\Phi_s \varepsilon_{mf}^3 \cong 1/14$$

Lampiran

Common Engineering Conversion Factors

Length	Volume
1 ft = 12 in = 0.3048 m, 1 yard = 3 ft 1 mi = 5280 ft = 1609.344 m 1 nautical mile (nmi) = 6076 ft	1 ft^3 = 0.028317 m^3 = 7.481 gal. 1 bbl = 42 U.S. gal 1 U.S. gal = 231 in^3 = 3.7853 L = 4 qt = 0.833 Imp. gal. 1 L = 0.001 m^3 = 0.035315 ft^3 = 0.2642 U.S. gal
Mass	**Density**
1 slug = 32.174 lb_m = 14.594 kg 1 lb_m = 0.4536 kg = 7000 grains	1 slug/ft^3 = 515.38 kg/m^3, 1 g/cm^3 = 1000 kg/m^3 1 lb_m/ft^3 = 16.0185 kg/m^3, 1 lb_m/in^3 = 27.68 g/cm^3
Acceleration & Area	**Velocity**
1 ft/s^2 = 0.3048 m/s^2 1 ft^2 = 0.092903 m^2	1 ft/s = 0.3048 m/s, 1 knot = 1 nmi/h = 1.6878 ft/s 1 mi/h = 1.4666666 ft/s (fps) = 0.44704 m/s
Mass Flow & Mass Flux	**Volume Flow**
1 slug/s = 14.594 kg/s. 1 lb_m/s = 0.4536 kg/s 1 kg/m^2-s = 0.2046 lb_m/ft^2-s = 0.00636 slug/ft^2-s	1 gal/min = 0.002228 ft^3/s = 0.06309 L/s 1 million gal/day = 1.5472 ft^3/s = 0.04381 m^3/s
Pressure	**Force and Surface Tension**
1 lb_f/ft^3 = 47.88 Pa, 1 torr = 1 mm Hg 1 psi = 144 psf, 1 bar = 10^5 Pa 1 atm = 2116.2 psf = 14.696 psi = 101, 325 Pa = 29.9 in. Hg = 33.9 ft H_2O	1 lb_f = 4.448222 N = 16 oz, 1 dyne = 1 g-cm/s^2 = 10^{-5} N 1 kg_f = 2.2046 lb_f = 9.80665 N 1 U.S. (short) ton = 2000 lb_f, 1 N = 0.2248 lb_f 1 N/m = 0.0685 lb_f /ft
Power	**Energy and Specific Energy**
1 hp = 550 (ft-lb_f)/s = 745.7 W 1 (ft-lb_f)/s = 1.3558 W 1 Watt = 3.4123 Btu/h = 0.00134 hp	1 ft-lb_f = 1.35582 J, 1 hp-h = 2544.5 Btu 1 Btu = 252 cal = 1055.056 J = 778.17 ft-lb_f 1 cal = 4.1855 J, 1 ft-lb_f /lb_m = 2.9890 J/kg
Specific Weight	**Heat Flux**
1 lb_f /ft^3 = 157.09 N/m^3	1 W/m^2 = 0.3171 Btu/(h-ft^2)
Viscosity	**Kinematic Viscosity**
1 slug/(ft-s) = 47.88 kg/(m-s) = 478.8 poise (p) 1 p=1 g/(cm-s)=0.1 kg/(m-s)=0.002088 slug/(ft-s)	1 ft^2/h = 2.506 .10^{-5} m^2/s, 1 ft^2/s = 0.092903 m^2/s 1 stoke (st) = 1 cm^2/s = 0.0001 m^2/s = 0.001076 ft^2/s
Temperature Scale Readings	
°F = (9/5)°C + 32 °C = (5/9) (°F – 32)	°R = °F + 459.69 °K = °C + 273.16
Specific Heat or Gas Constant*	**Thermal Conductivity***
1 (ft-lb_f)/(slug-°R) = 0.16723 (N-m) (kg-K) 1 Btu/(lb-°R) = 4186.8 J/(kg-K)	1 cal/(s-cm-°C) = 242 Btu/(h-ft-°R) 1 Btu/(h-ft-°R) = 1.7307 W/(m-K)

- Note that the intervals in absolute (Kelvin) and °C are equal. Also, 1 °R = 1 °F.

Latent heat: 1 J/kg = 4.2995 x 10-4 Btu/lb_m = 10.76 lb_f-ft/slug = 0.3345 lb_f– ft/lb_m, 1 Btu/lb_m = 2325.9 J/kg.
Heat transfer coefficient: 1 Btu/(h-ft^2-°F) = 5.6782 W/(m^2 - °C).
Heat generation rate: 1 W/m^3 = 0.09665 Btu/(h-ft^3)
Heat transfer per unit length: 1 W/m = 1.0403 Btu/(h-ft)
Mass transfer coefficient: 1 m/s = 11.811 ft/h, 1 lbmol/(h-ft^2) = .0013562 kgmol/(s-m^2)

Dimensions of Standard Steel Pipe

Nominal Pipe Size (in.)	*Outside Diameter*		*Schedule Number*	*Wall Thickness*		*Inside Diameter*		*Inside Cross-Sectional Area*	
	in.	*mm*		*in.*	*mm*	*in.*	*mm*	*ft²*	*m² × 10⁴*
$\frac{1}{8}$	0.405	10.29	40	0.068	1.73	0.269	6.83	0.00040	0.3664
			80	0.095	2.41	0.215	5.46	0.00025	0.2341
$\frac{1}{4}$	0.540	13.72	40	0.088	2.24	0.364	9.25	0.00072	0.6720
			80	0.119	3.02	0.302	7.67	0.00050	0.4620
$\frac{3}{8}$	0.675	17.15	40	0.091	2.31	0.493	12.52	0.00133	1.231
			80	0.126	3.20	0.423	10.74	0.00098	0.9059
$\frac{1}{2}$	0.840	21.34	40	0.109	2.77	0.622	15.80	0.00211	1.961
			80	0.147	3.73	0.546	13.87	0.00163	1.511
$\frac{3}{4}$	1.050	26.67	40	0.113	2.87	0.824	20.93	0.00371	3.441
			80	0.154	3.91	0.742	18.85	0.00300	2.791
1	1.315	33.40	40	0.133	3.38	1.049	26.64	0.00600	5.574
			80	0.179	4.45	0.957	24.31	0.00499	4.641
$1\frac{1}{4}$	1.660	42.16	40	0.140	3.56	1.380	35.05	0.01040	9.648
			80	0.191	4.85	1.278	32.46	0.00891	8.275
$1\frac{1}{2}$	1.900	48.26	40	0.145	3.68	1.610	40.89	0.01414	13.13
			80	0.200	5.08	1.500	38.10	0.01225	11.40
2	2.375	60.33	40	0.154	3.91	2.067	52.50	0.02330	21.65
			80	0.218	5.54	1.939	49.25	0.02050	19.05
$2\frac{1}{2}$	2.875	73.03	40	0.203	5.16	2.469	62.71	0.03322	30.89
			80	0.276	7.01	2.323	59.00	0.02942	27.30
3	3.500	88.90	40	0.216	5.49	3.068	77.92	0.05130	47.69
				0.300	7.62	2.900	73.66	0.04587	42.61
$3\frac{1}{2}$	4.000	101.6	40	0.226	5.74	3.548	90.12	0.06870	63.79
			80	0.318	8.08	3.364	85.45	0.06170	57.35
4	4.500	114.3	40	0.237	6.02	4.026	102.3	0.08840	82.19
			80	0.337	8.56	3.826	97.18	0.07986	74.17
5	5.563	141.3	40	0.258	6.55	5.047	128.2	0.1390	129.1
			80	0.375	9.53	4.813	122.3	0.1263	117.5
6	6.625	168.3	40	0.280	7.11	6.065	154.1	0.2006	186.5
			80	0.432	10.97	5.761	146.3	0.1810	168.1
8	8.625	219.1	40	0.322	8.18	7.981	202.7	0.3474	322.7
			80	0.500	12.70	7.625	193.7	0.3171	294.7

...3/-

Physical Properties of Water

Density of Liquid Water

Temperature		Density		Temperature		Density	
K	*°C*	*g/cm³*	*kg/m³*	*K*	*°C*	*g/cm³*	*kg/m³*
273.15	0	0.99987	999.87	323.15	50	0.98807	988.07
277.15	4	1.00000	1000.00	333.15	60	0.98324	983.24
283.15	10	0.99973	999.73	343.15	70	0.97781	977.81
293.15	20	0.99823	998.23	353.15	80	0.97183	971.83
298.15	25	0.99708	997.08	363.15	90	0.96534	965.34
303.15	30	0.99568	995.68	373.15	100	0.95838	958.38
313.15	40	0.99225	992.25				

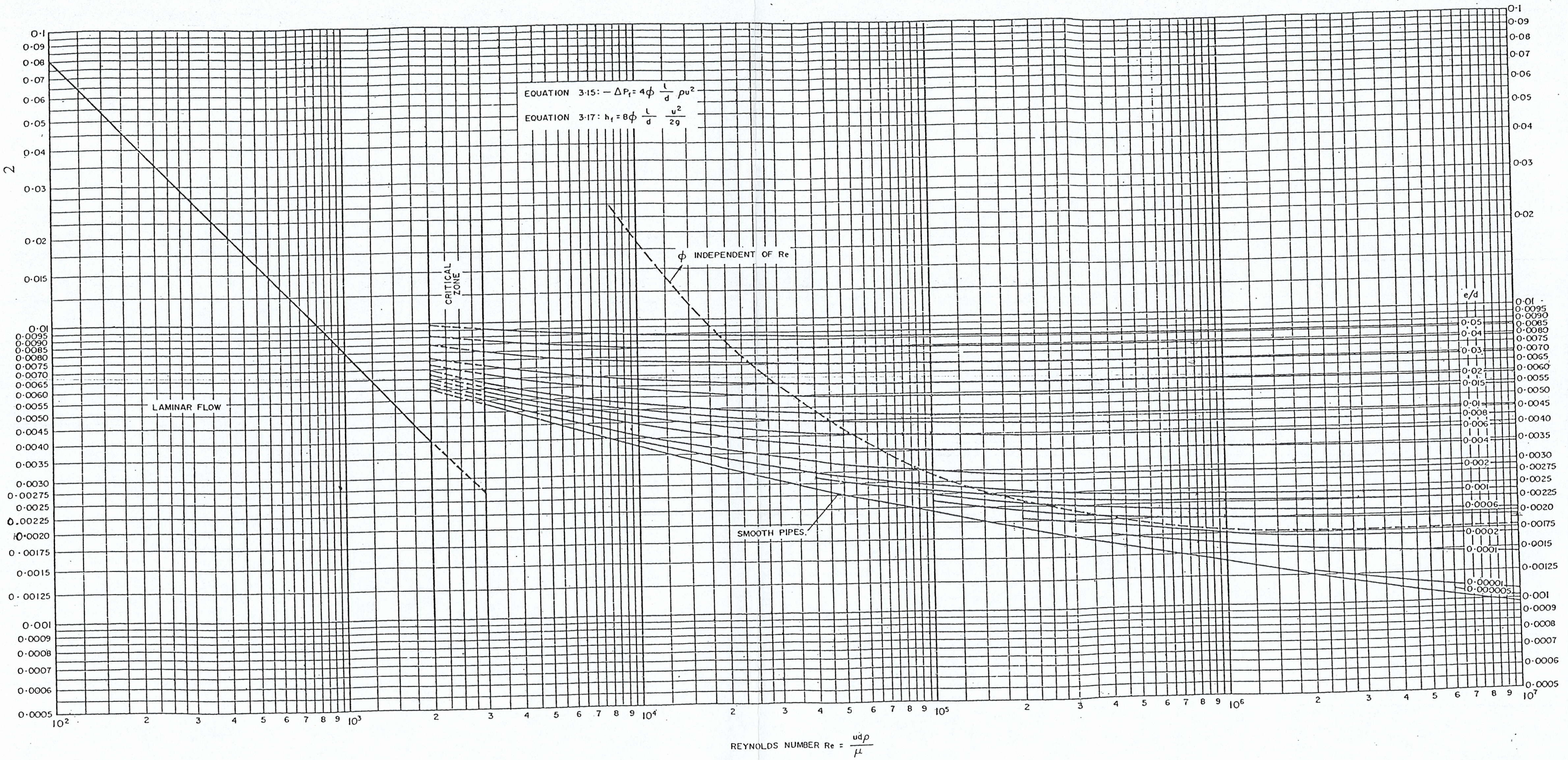
Source: R. H. Perry and C. H. Chilton, *Chemical Engineers' Handbook*, 5th ed. New York: McGraw-Hill Book Company, 1973. With permission.

Viscosity of Liquid Water

Temperature		Viscosity [(Pa · s) 10^3, (kg/m · s) 10^3, or cp]	Temperature		Viscosity [(Pa · s) 10^3, (kg/m · s) 10^3, or cp]
K	*°C*		*K*	*°C*	
273.15	0	1.7921	323.15	50	0.5494
275.15	2	1.6728	325.15	52	0.5315
277.15	4	1.5674	327.15	54	0.5146
279.15	6	1.4728	329.15	56	0.4985
281.15	8	1.3860	331.15	58	0.4832
283.15	10	1.3077	333.15	60	0.4688
285.15	12	1.2363	335.15	62	0.4550
287.15	14	1.1709	337.15	64	0.4418
289.15	16	1.1111	339.15	66	0.4293
291.15	18	1.0559	341.15	68	0.4174
293.15	20	1.0050	343.15	70	0.4061
293.35	20.2	1.0000	345.15	72	0.3952
295.15	22	0.9579	347.15	74	0.3849
297.15	24	0.9142	349.15	76	0.3750
298.15	25	0.8937	351.15	78	0.3655
299.15	26	0.8737	353.15	80	0.3565
301.15	28	0.8360	355.15	82	0.3478
303.15	30	0.8007	357.15	84	0.3395
305.15	32	0.7679	359.15	86	0.3315
307.15	34	0.7371	361.15	88	0.3239
309.15	36	0.7085	363.15	90	0.3165
311.15	38	0.6814	365.15	92	0.3095
313.15	40	0.6560	367.15	94	0.3027
315.15	42	0.6321	369.15	96	0.2962
317.15	44	0.6097	371.15	98	0.2899
319.15	46	0.5883	373.15	100	0.2838
321.15	48	0.5683			

Source: Bingham, *Fluidity and Plasticity*. New York: McGraw-Hill Book Company, 1922. With permission.

...5/-



Pipe friction chart ϕ versus *Re*.